Update on the EIC Fast Simulator

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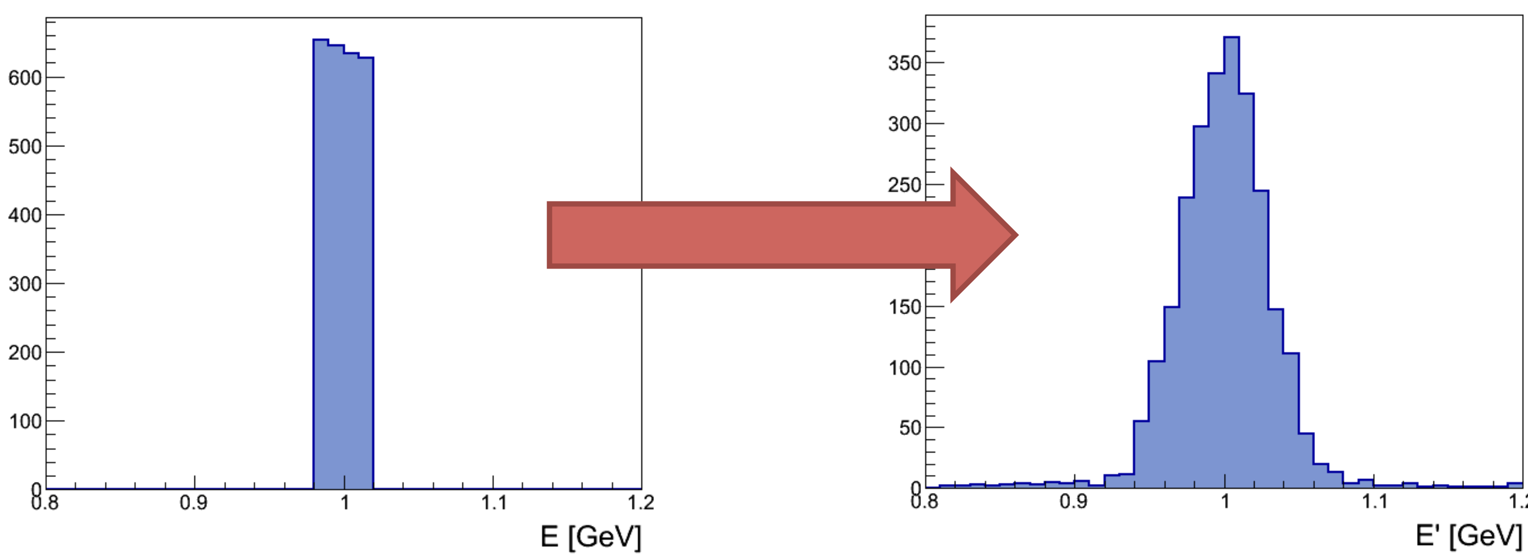
June 22, 2012

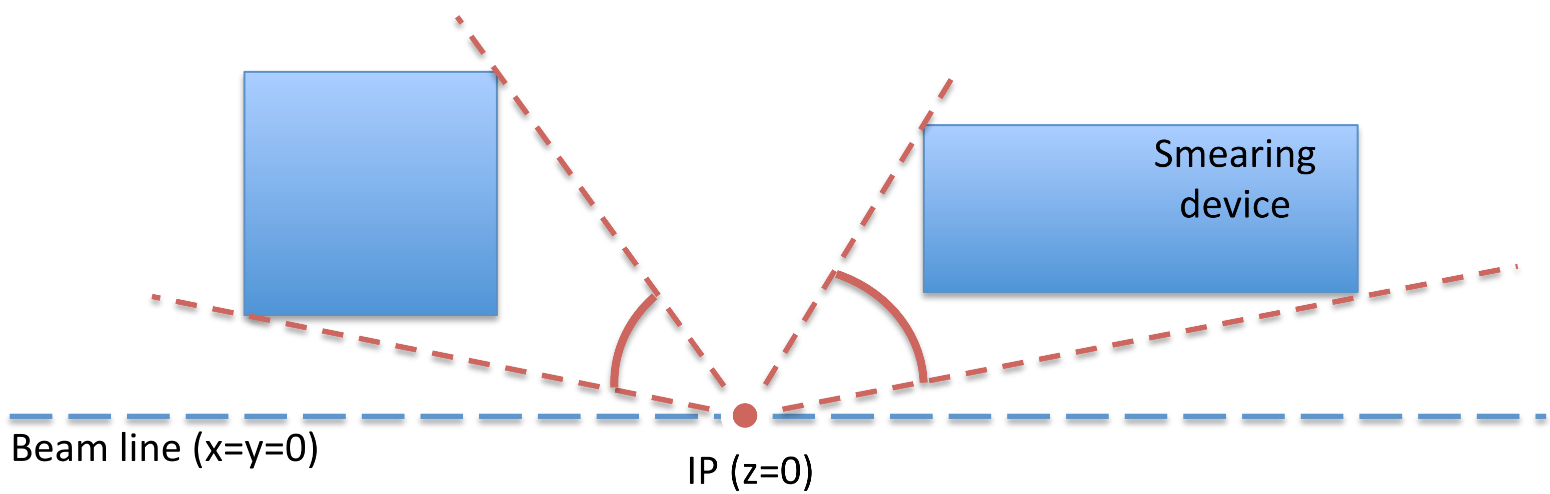
What is it?

- A way to apply approximate detector-level effects to simulated data
  - Kinematics (pT, E, Θ, ϕ) of final-state particles "smeared" according to Gaussian with width given by a parametrized resolution
  - Considerably faster and more flexible than a full GEANT detector simulation (good as first-order approximation)



How it works

- Logical volumes ("devices") are created based on possible detector geometries
- Acceptance conditions and smearing rules for each device are set
  - Cuts on particle type, angle, momentum…
  - If a final state particle meets conditions, relevant kinematics are smeared (E for calorimeters, p for tracking, etc..)



Electromagnetic Calorimeters

- Smears energy of electrons and photons (e,γ)
  - Central region ($-1 < \eta < 1$) based on joint proposal from PHENIX/STAR/eRHIC (BNL):

$$\frac{\sigma}{E} = \frac{0.122}{\sqrt{E}}$$

  - Forward/backward ($1 < |\eta| < 5$) we assume a lead tungstate crystal calorimeter with resolution similar to anticipated PANDA (GSI):

$$\frac{\sigma}{E} = \frac{0.0178}{\sqrt{E}} + 0.0069$$

Hadronic Calorimeter

- Smears energy of hadrons ($\pi^{\pm}$, $K^{\pm}$, p, …)
  - For now we assume HERA response:

$$\frac{\sigma}{E} = \frac{0.35}{\sqrt{E}}$$

Tracking

- Smears momentum measured from curvature of charged particles in magnetic field
- Contributions from **intrinsic finite resolution (σ_i)** and **multiple scattering (σ_{MS})**

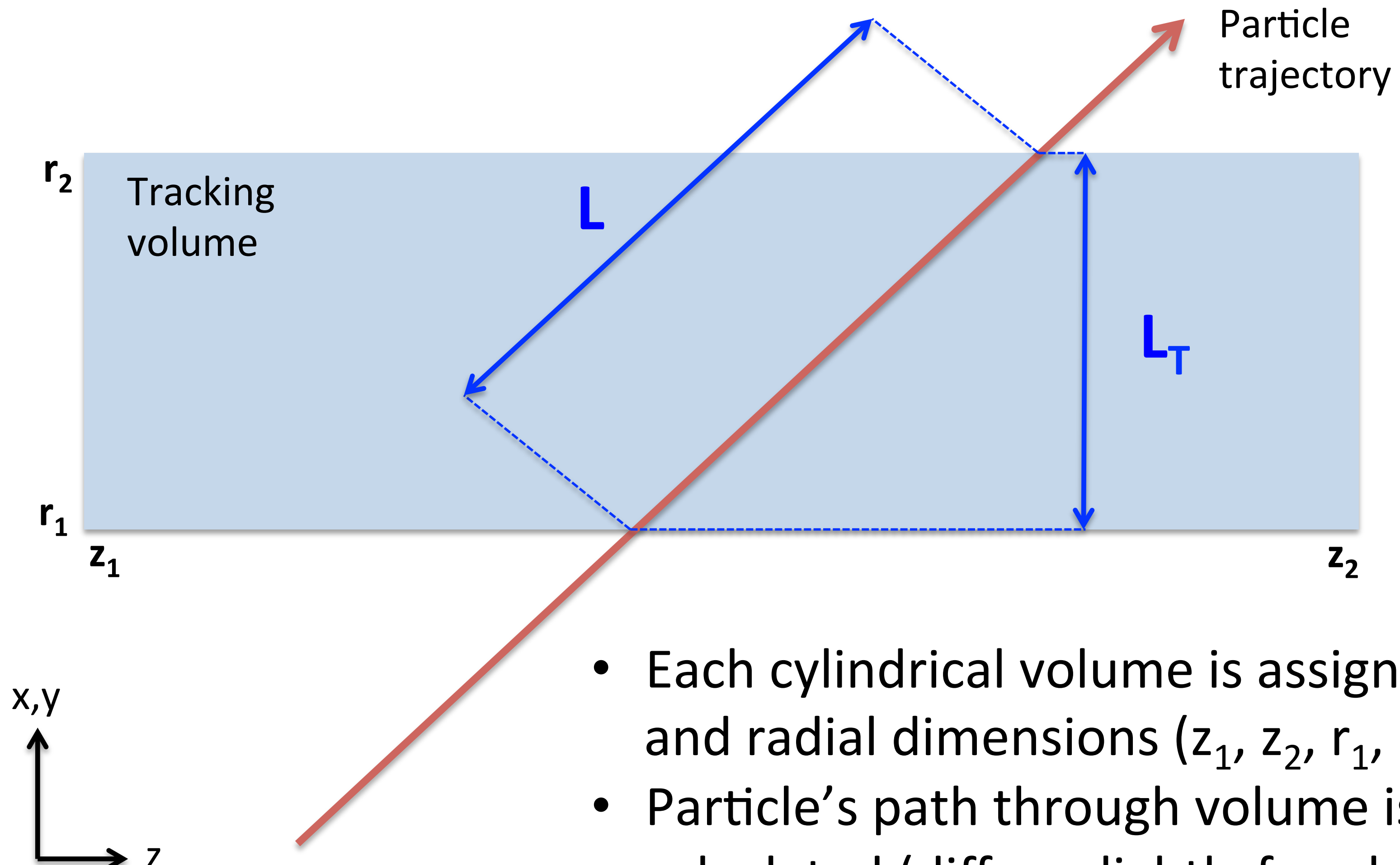
$$\left(\frac{\sigma_{p_T}}{p_T}\right)_i = \frac{p_T}{0.3B}\frac{\sigma_{r\phi}}{L_T^2}\sqrt{\frac{720n^3}{(n-1)(n+1)(n+2)(n+3)}}$$

$$\left(\frac{\sigma_{p_T}}{p_T}\right)_{MS} = \frac{0.0136}{0.3BL\beta}\sqrt{n_{rl}}$$

$$\sigma = \sqrt{\sigma_{MS}^2 + \sigma_i^2}$$

B = magnetic field
L = total path length
L_T = transverse path length
$\sigma_{r\phi}$ = space-point resolution
n = num. space points
n_{rl} = num. rad lengths

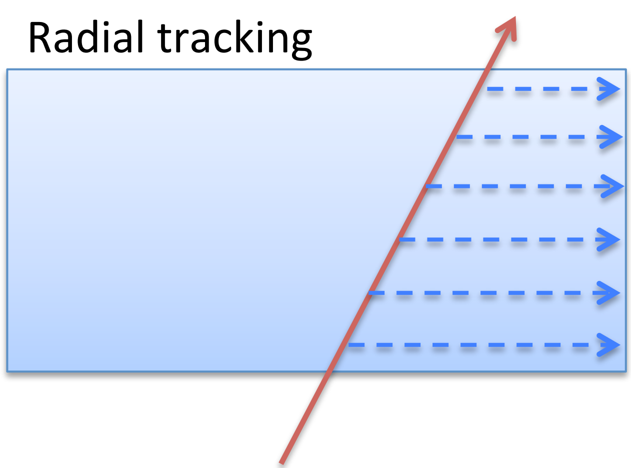
Tracking

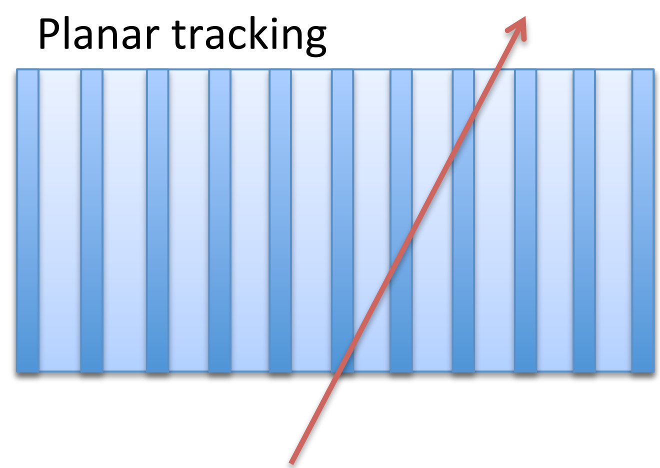


- Each cylindrical volume is assigned z and radial dimensions (z_1, z_2, r_1, r_2)
- Particle's path through volume is calculated (differs slightly for planar vs. radial trackers… see next slide!)

Tracking

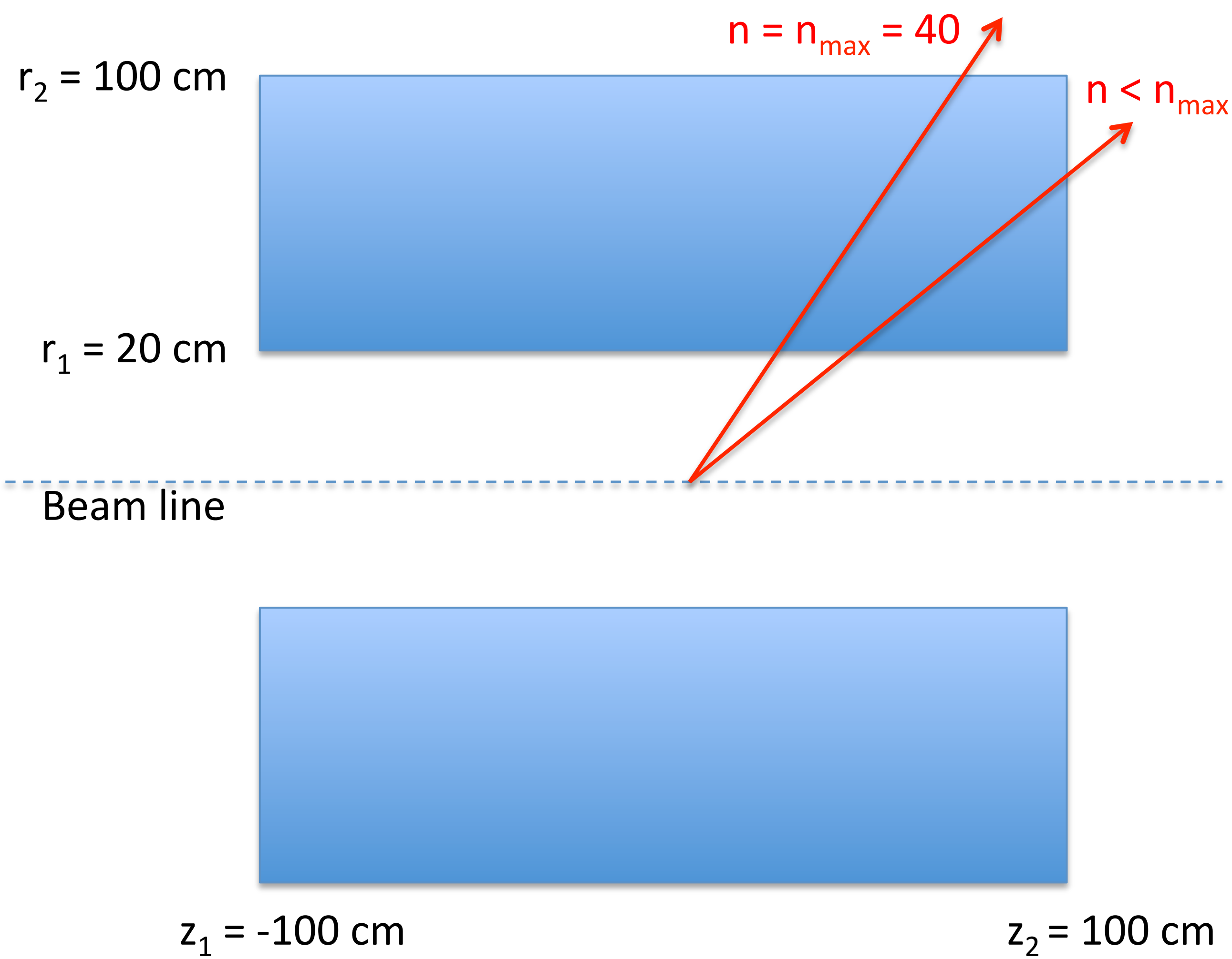
- Two types of tracking volumes for more realistic calculation of number of space points:
  - **Radial tracker (drift chamber)**
  - **Planar tracker (vertical GEM layers)**





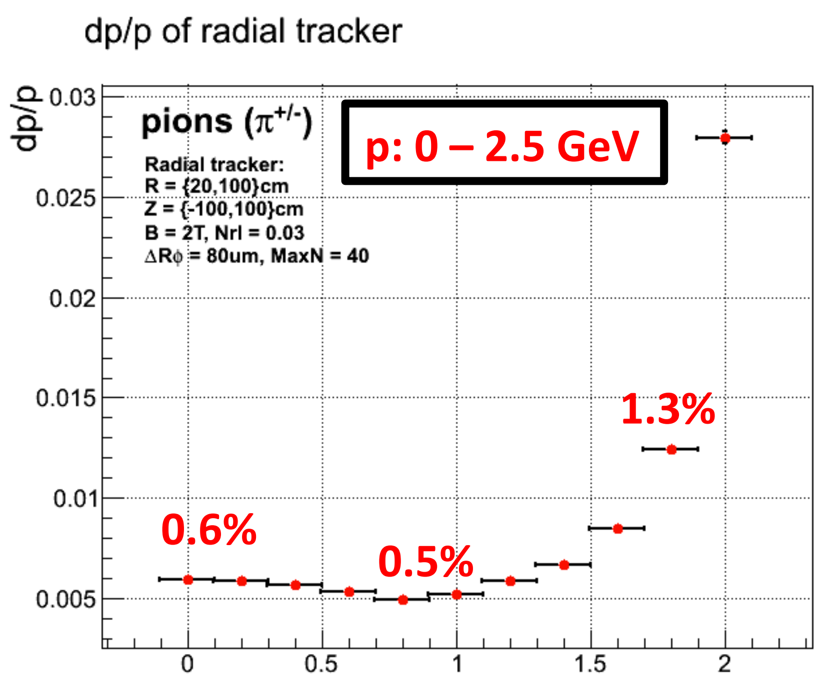
Testing the radial tracker:

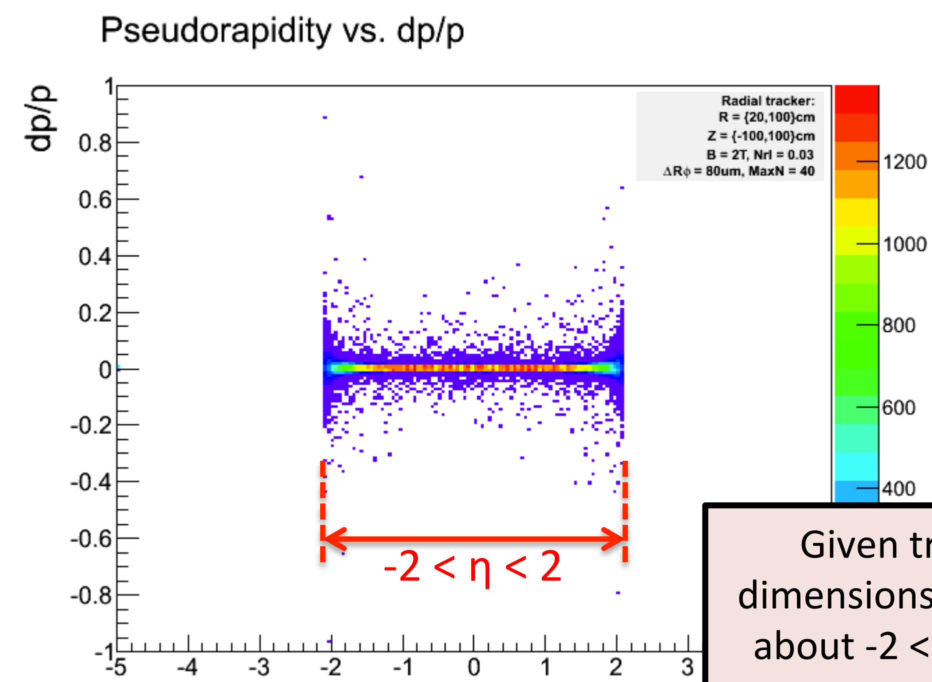
– trial geometry shown below

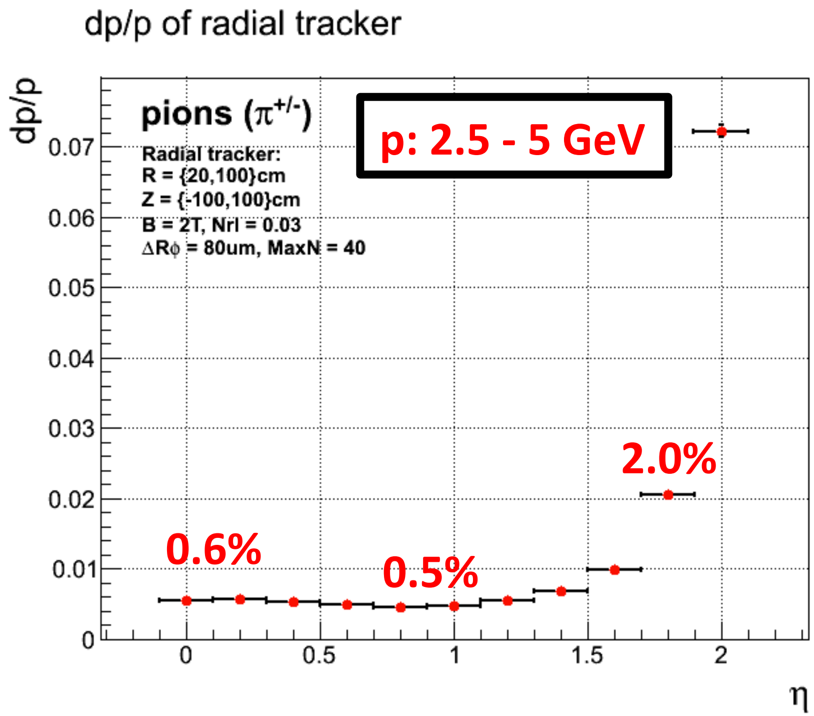


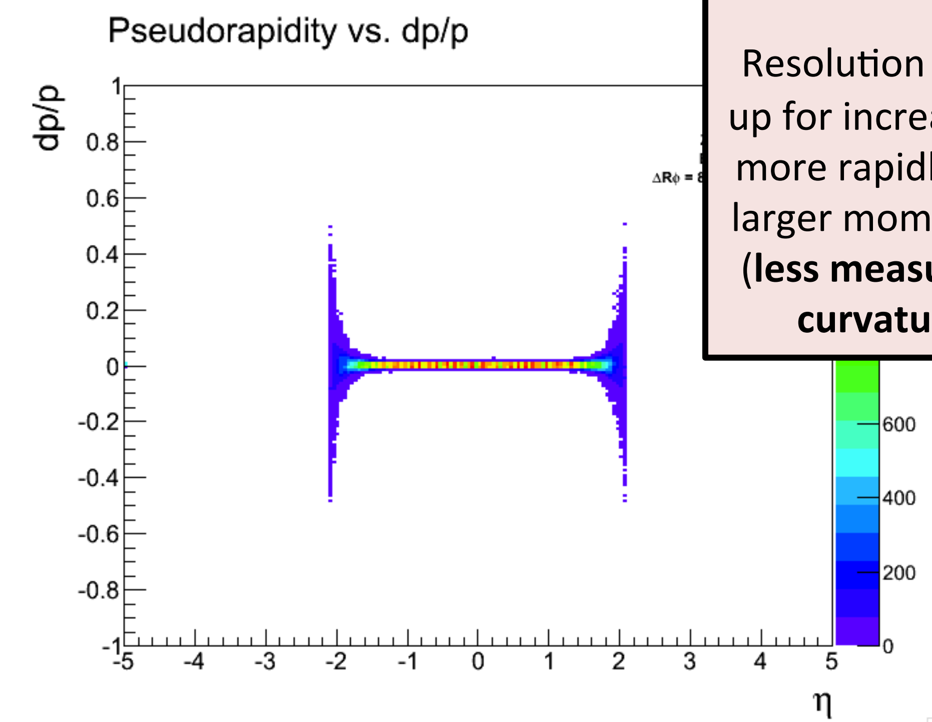
Number of hit points: calculated as fraction of total possible transverse distance of volume

Accepts: only particles with at least n=3 points







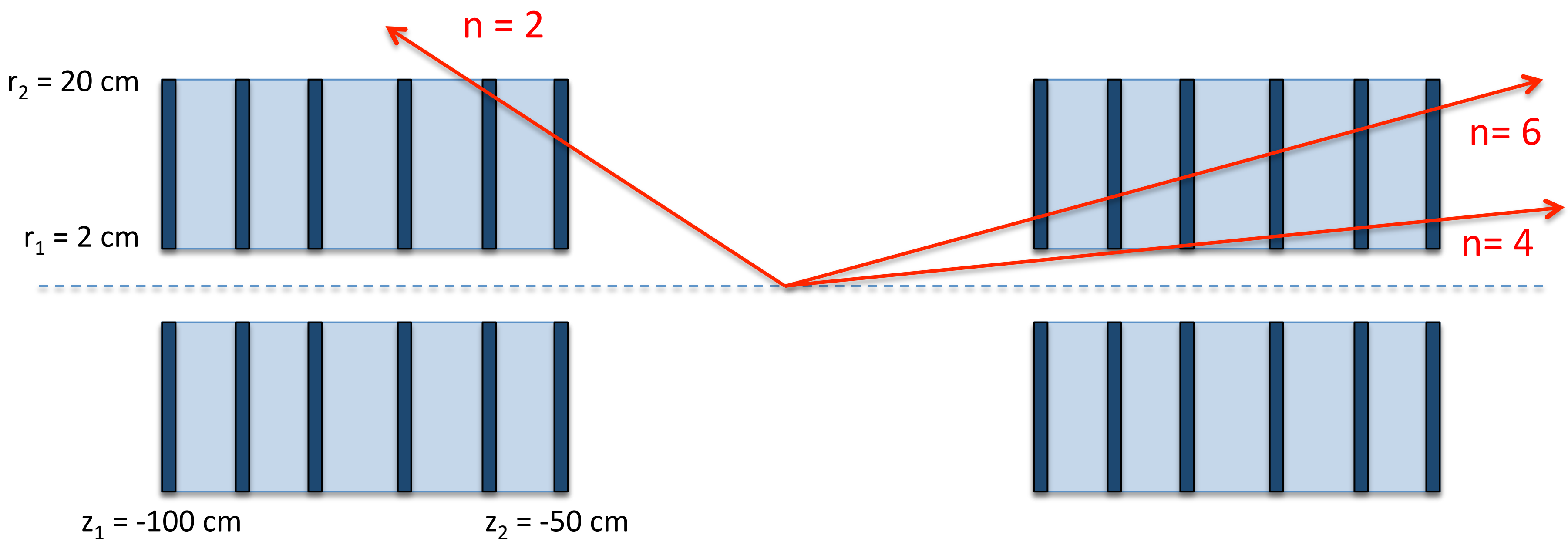


Given trial dimensions cover about -2 < η < 2

Resolution blows up for increasing η more rapidly with larger momentum (**less measurable curvature**)

Testing the planar tracker

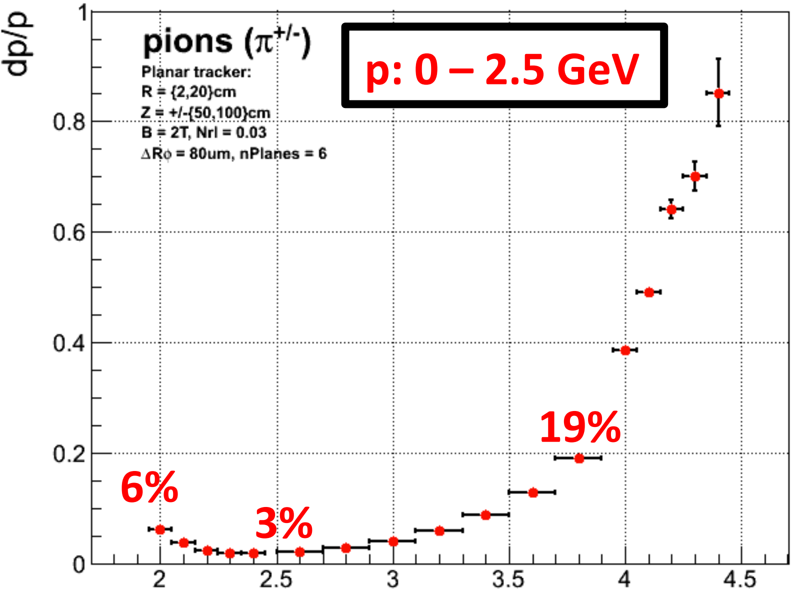
– symmetric forward/backward volumes of 6 evenly-spaced layers



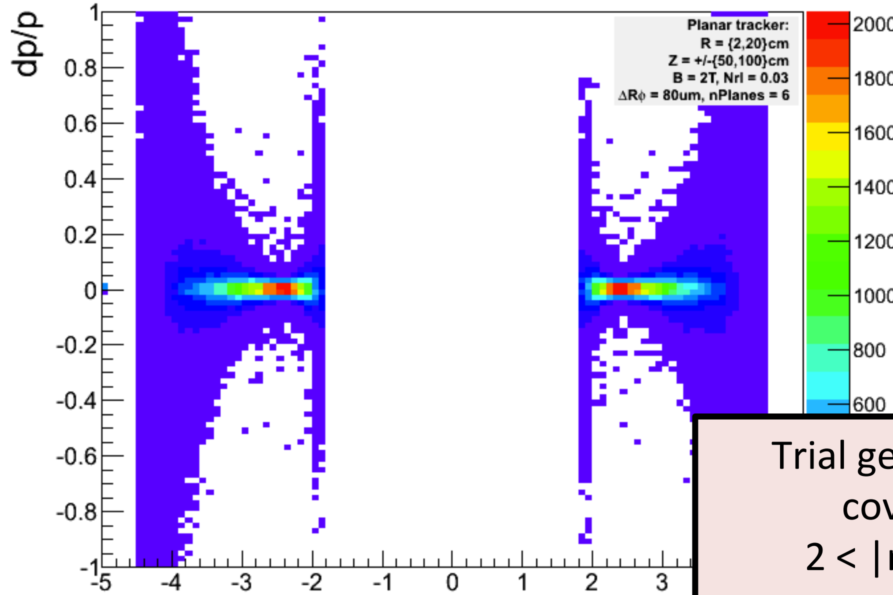
Number of hit points: calculated as number of GEM planes the particle passes through

Accepts: only particles with at least n=3 points

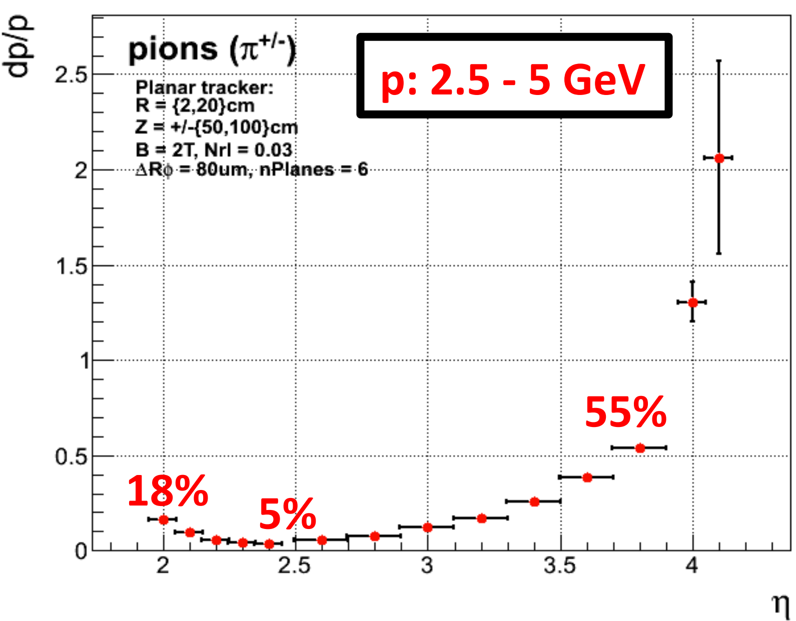
dp/p of planar tracker



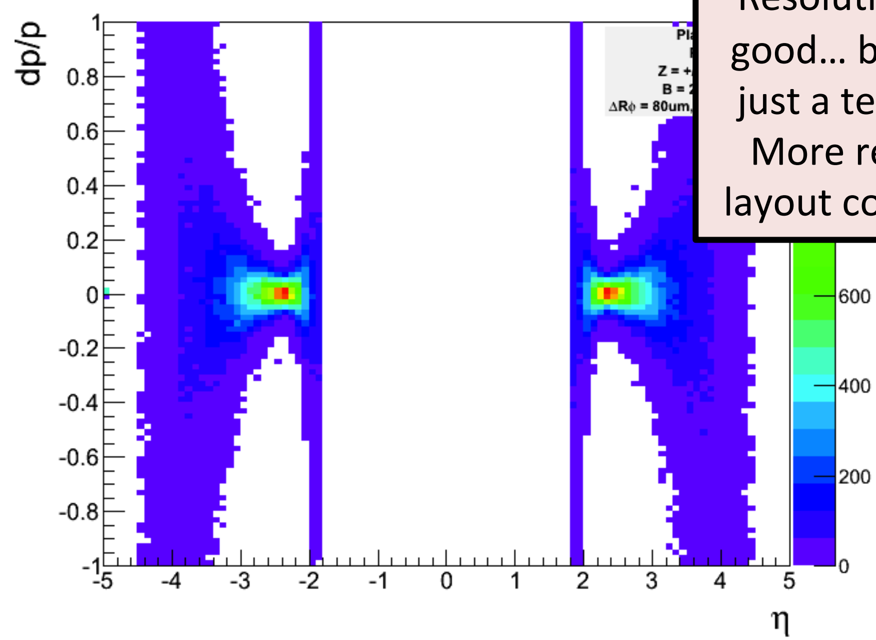
Pseudorapidity vs. dp/p



dp/p of planar tracker



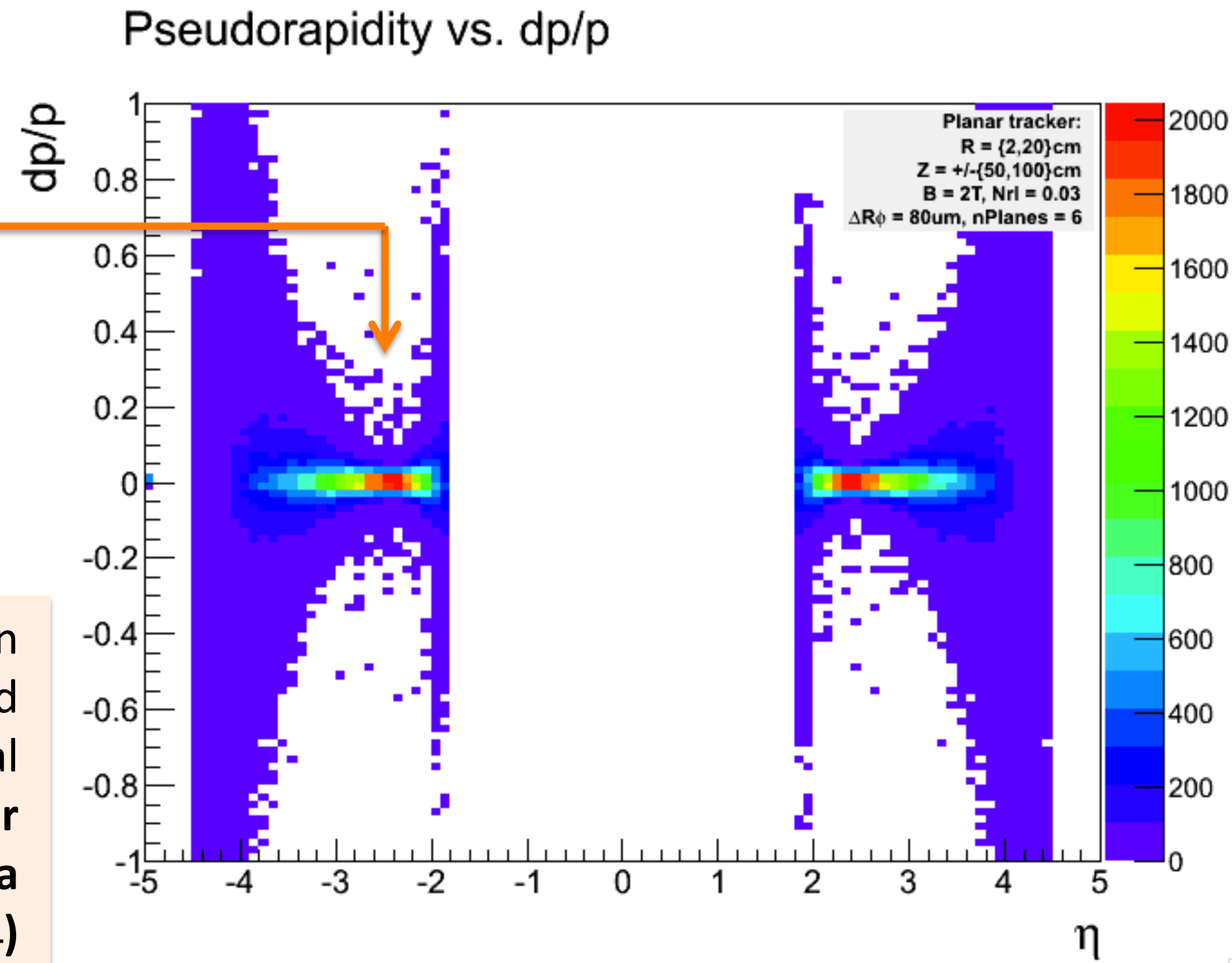
Pseudorapidity vs. dp/p



Trial geometry covers
$2 < |\eta| < 4$

Resolution not too good… but this was just a test anyway. More reasonable layout coming soon.

Resolution best where particles pass through **max # of planes** and have **largest track length**

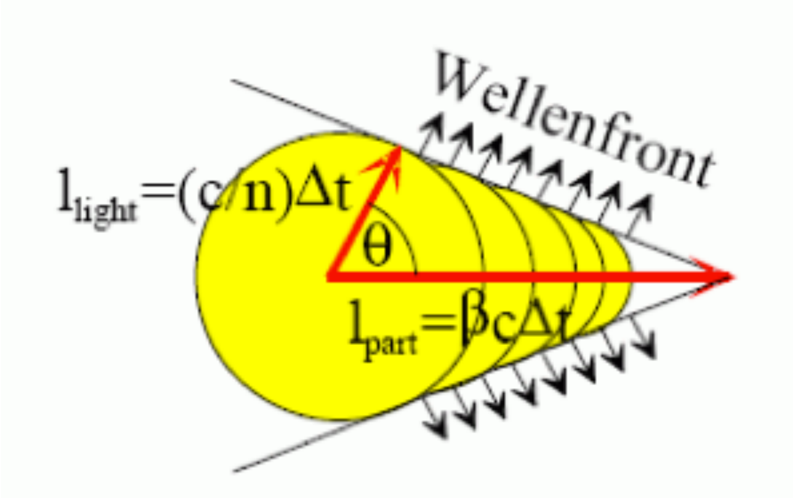


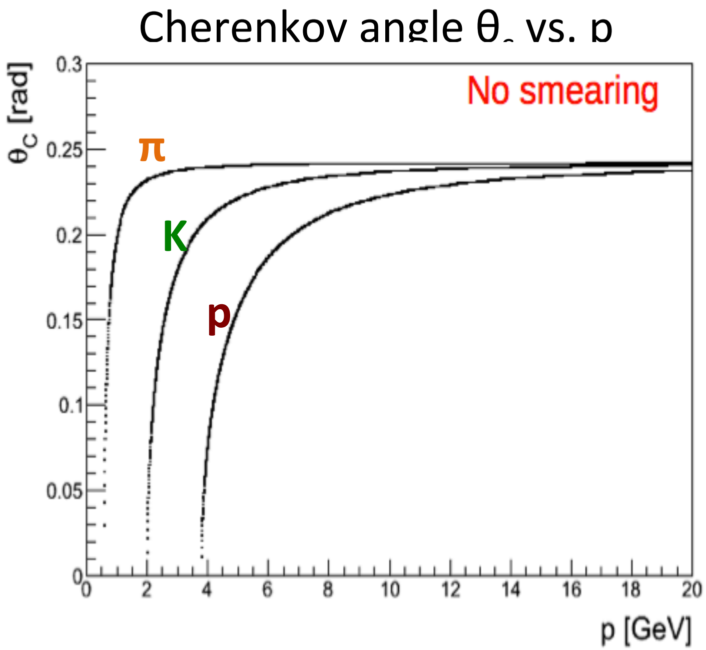
Resolution worse in forward/backward regions than for central due to **smaller transverse momenta (σ prop. to $1/L_T$)**

Fast PID Studies

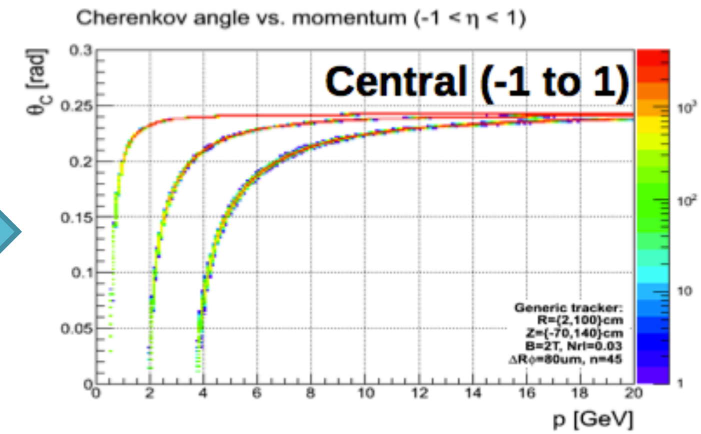
- **Goal**: extrapolate resolution from tracking to gauge PID efficiency of forward aerogel RICH
  - Implement realistic PID function into smearing

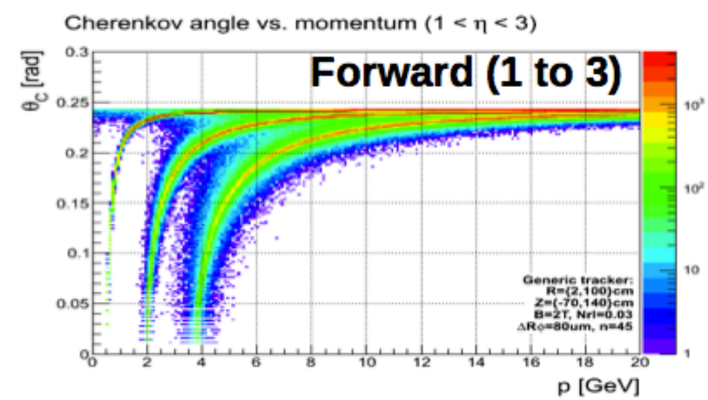
$$\cos\theta_c = \frac{c}{n\beta c} = \frac{1}{n\beta}$$

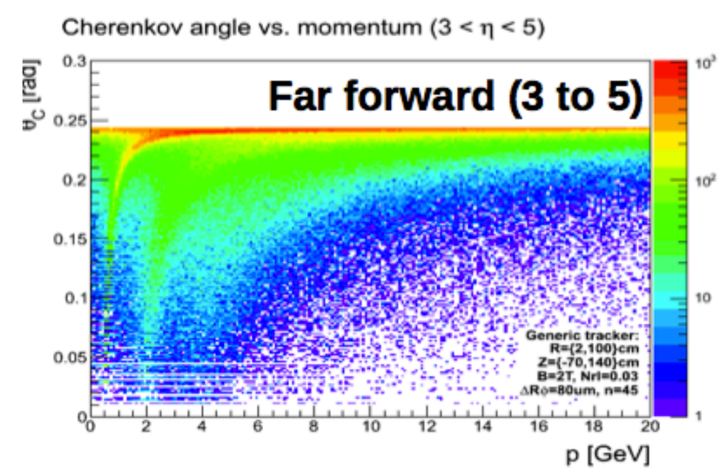




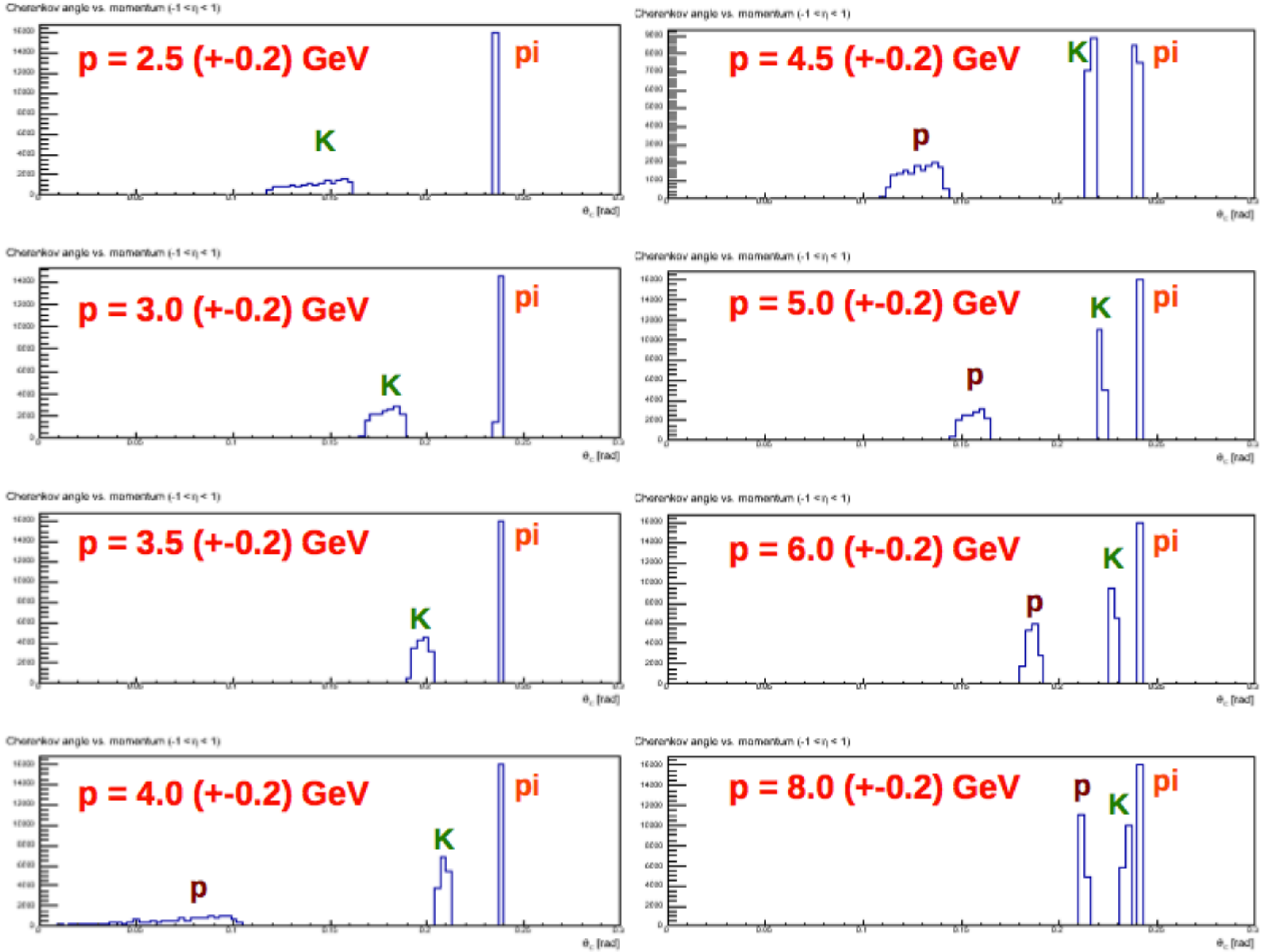
p-axis smeared by tracking!





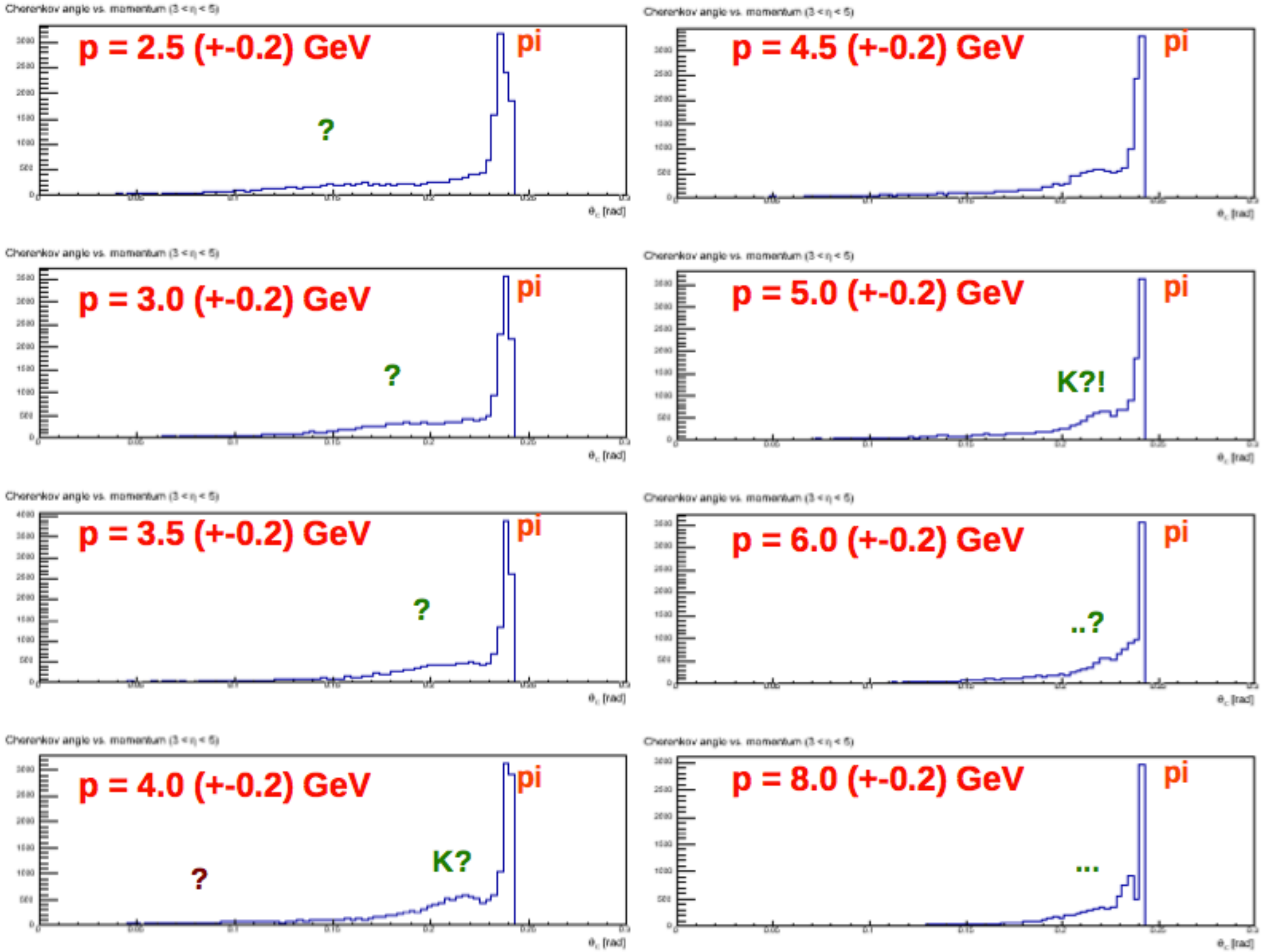


- Uniform radial-tracking volume used in these plots
- **With worsening resolution at large rapidity, particles harder to distinguish**



Central region (-1 < eta < 1)

Very defined + well-separated peaks in
cherenkov angle up to 8 GeV
(smearing negligible)



Far forward region (3 < eta < 5)

- Smearing substantial; peaks are sloppily reconstructed and merge into one another
- kaons become better differentiated around 4 GeV

Fast PID Studies

- Particle mis-identification probability matrix already built into fast simulator framework
  - For bins in [“measured”] momentum, particles have chance of being assigned a different ID
  - Custom PID matrices very easy to create in separate txt files
- **Need to look at overlap of peaks in θ_C plots to determine matrix values**

- For more information and to keep updated on progress, visit the Wiki:

  https://wiki.bnl.gov/eic/index.php/Namespace_Smear

- ROOT/C++ macro used to produce most of the plots shown here is stored on RACF (code is a bit messy at the moment.. read at own risk):

  /direct/eic+u/wforeman/smear/res.c

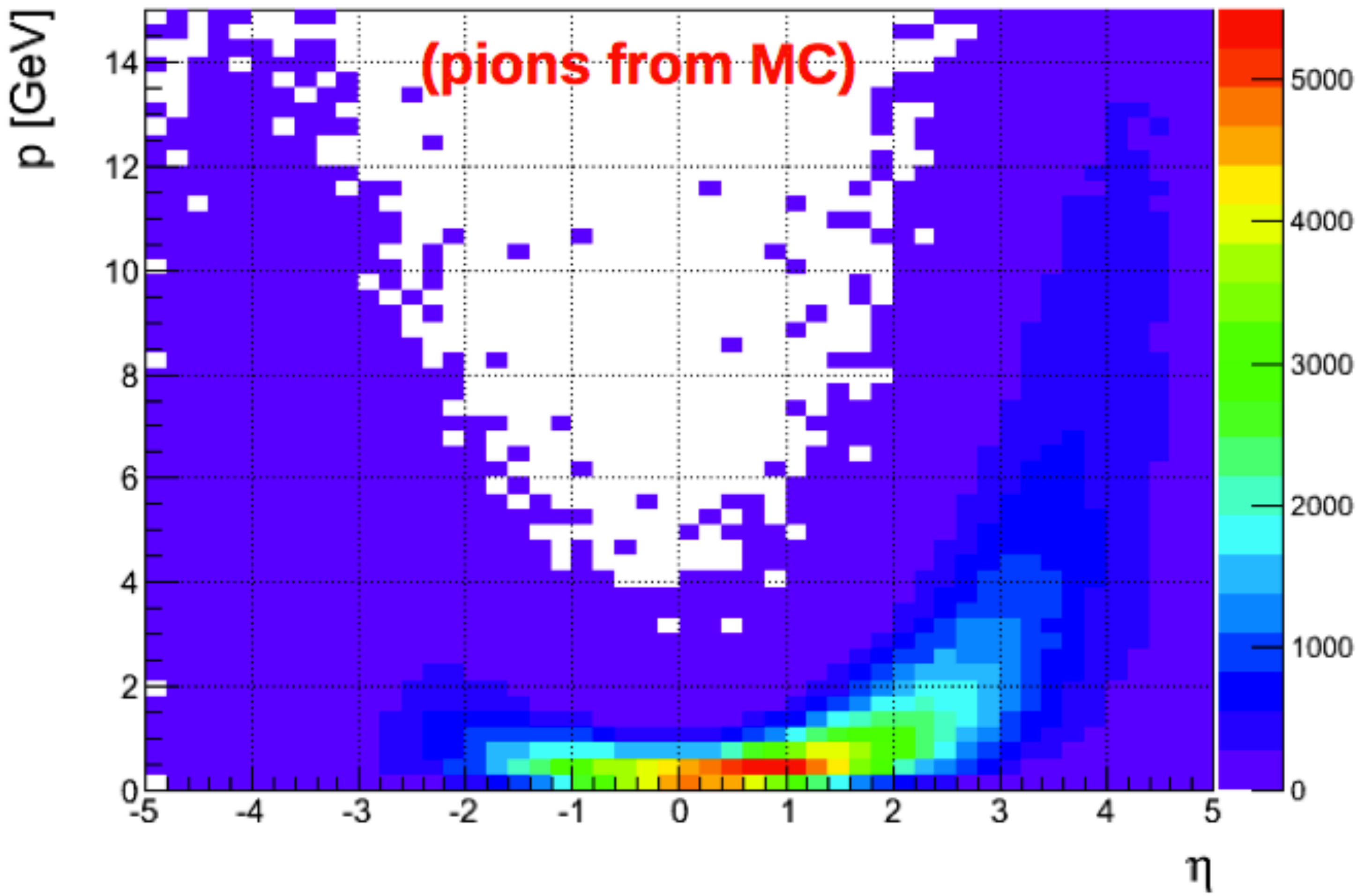
Extras

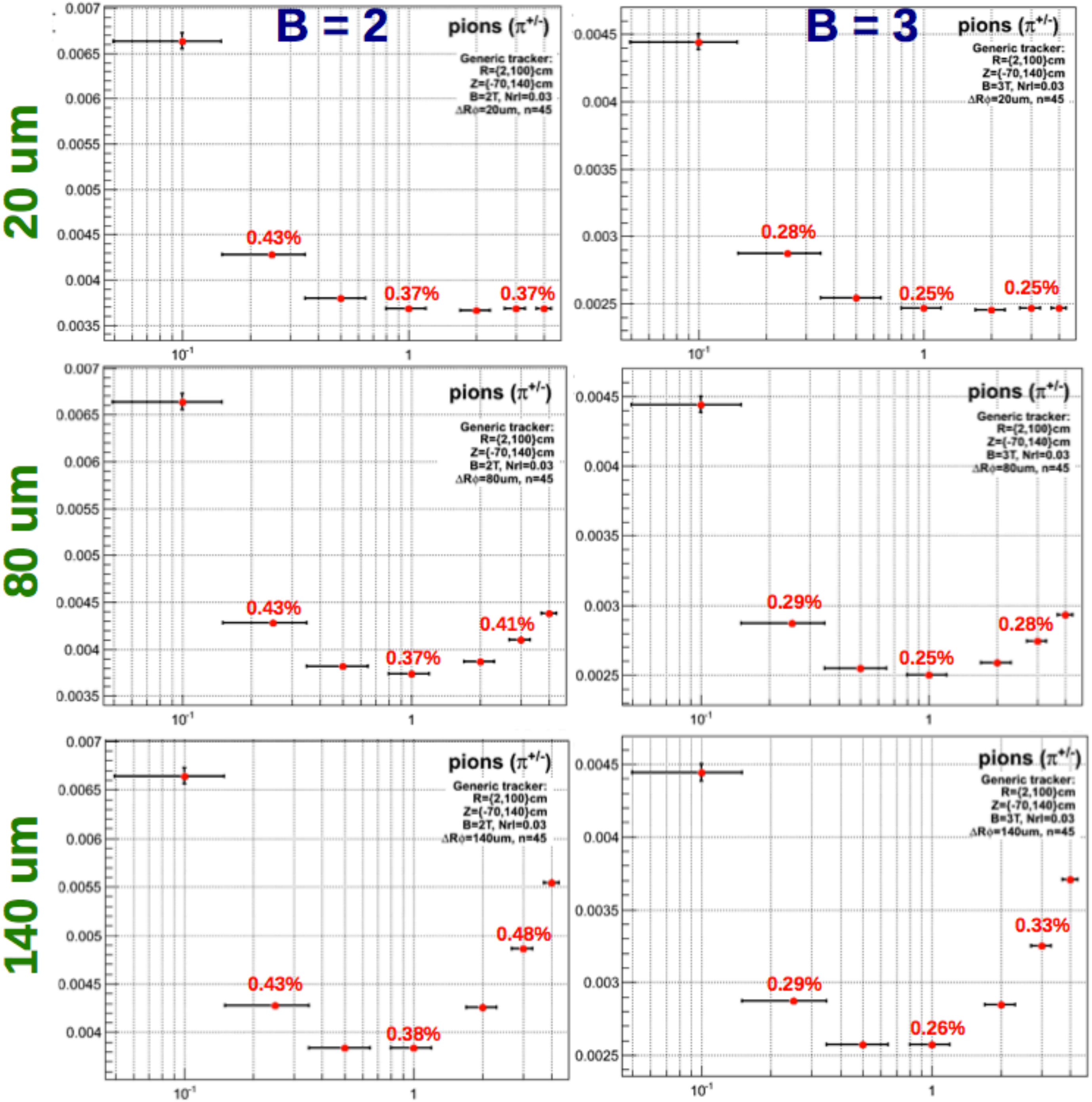
Angular/momentum distribution of final state pions

In central ($|\eta|<1$), most π's have p < 1 GeV

In forward ($1<\eta<3$), p < 4 GeV

Even for far-forward, π's rarely exceed 10 GeV

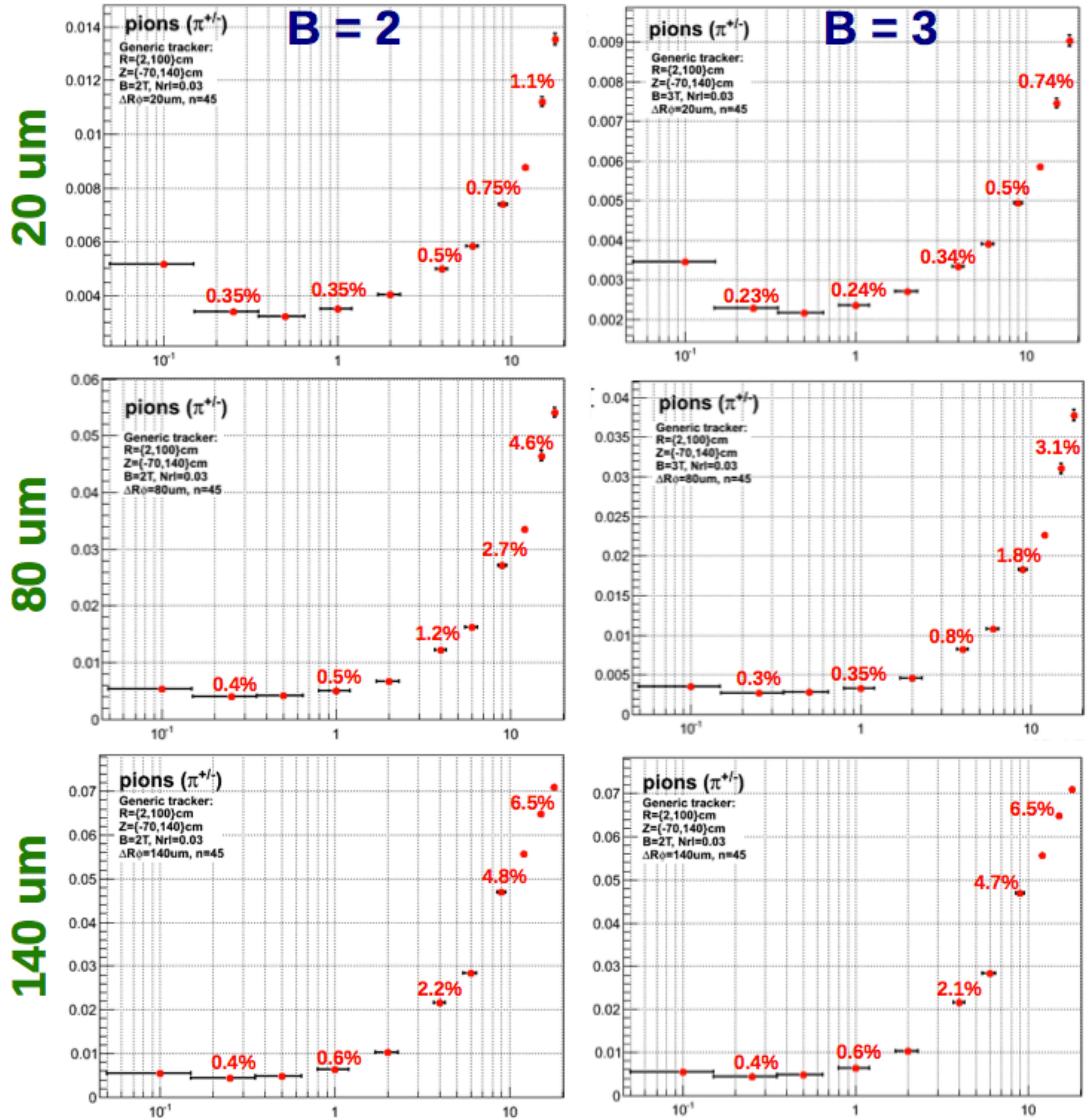




I. CENTRAL REGION (-1 < eta < 1)

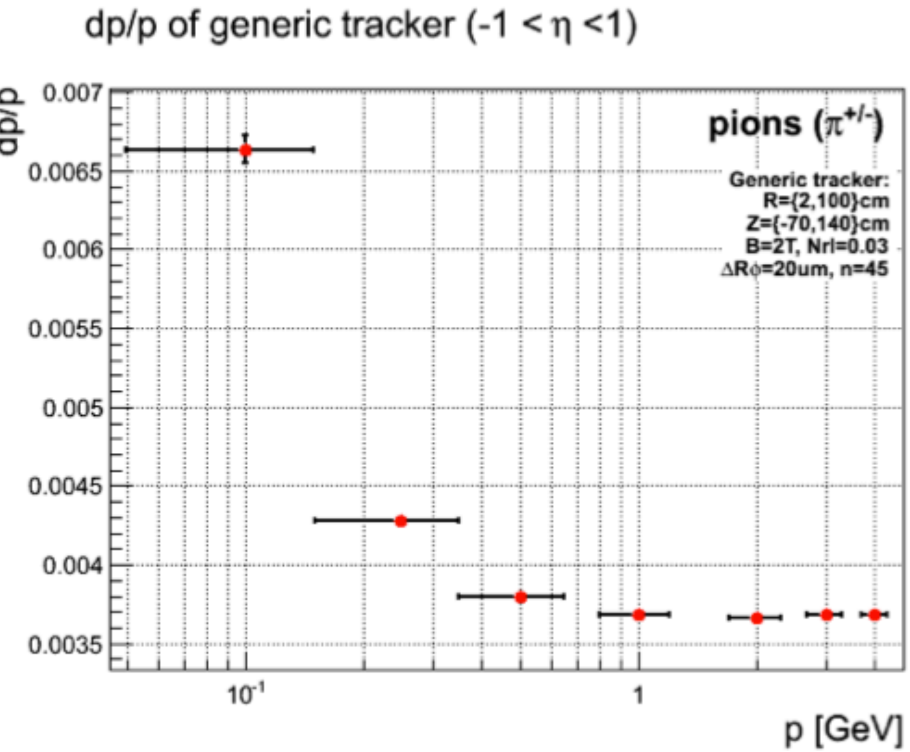
- Noticeable changes in dp/p plots for different parameters (B and spatial resolution of silicon)
- Upward trend for larger momenta is exaggerated for courser resolution (from 20um to 140um)
- Smearing of low p pions (< 1 GeV) relatively unchanged

- **Rough estimates of dp/p for p={0.25, 1, 3} GeV shown in red**

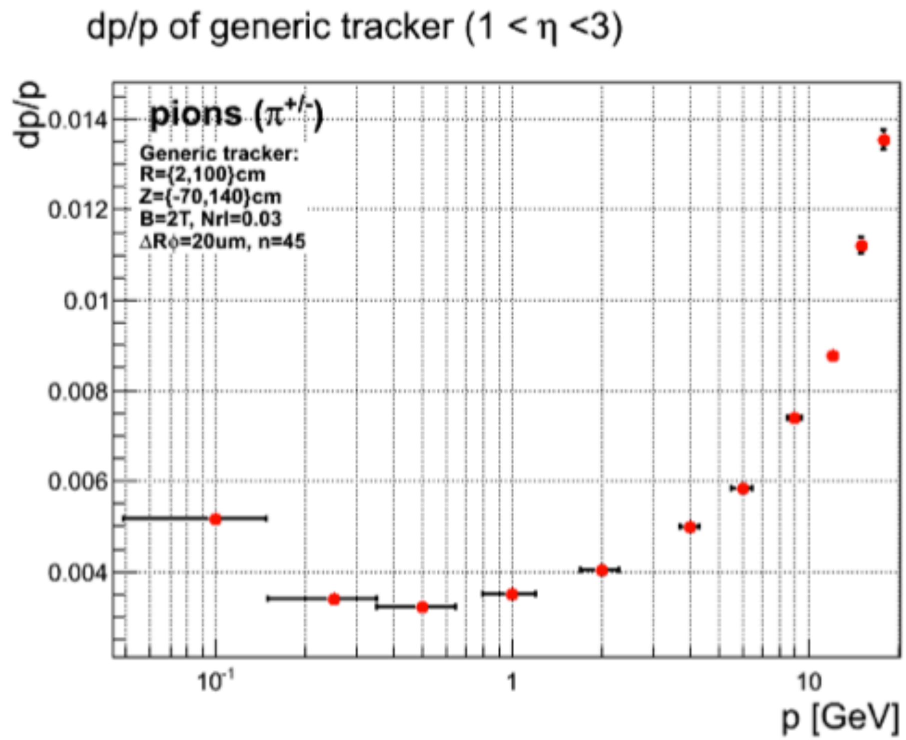


II. FORWARD REGION (1 < eta < 3)

- Rough estimates of dp/p for p = {0.25, 1, 4, 9, 15} GeV shown in red



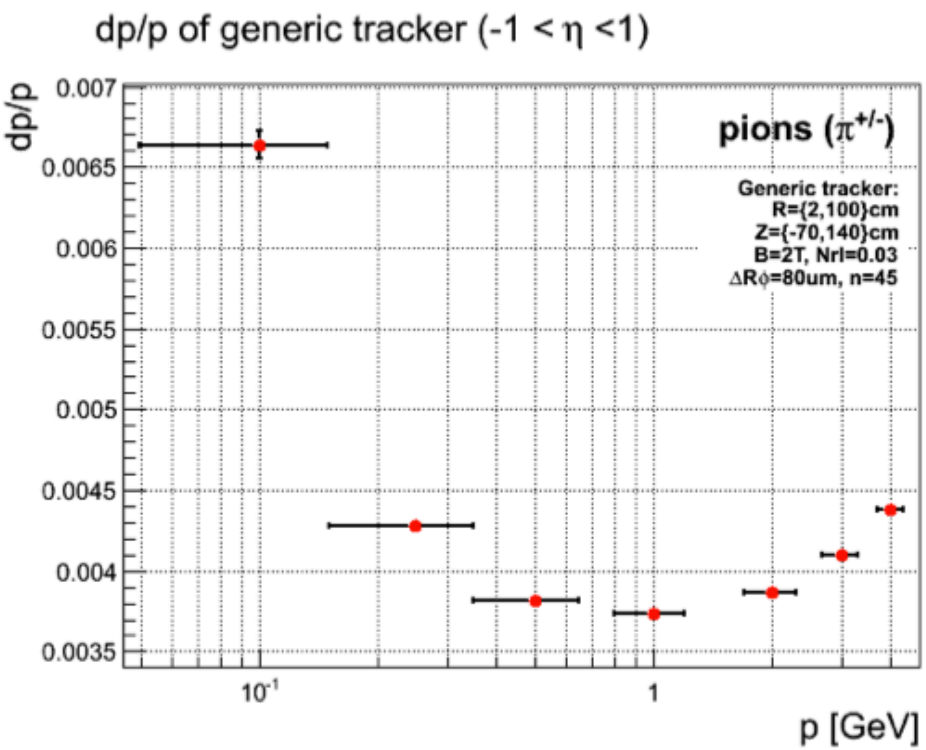
Central



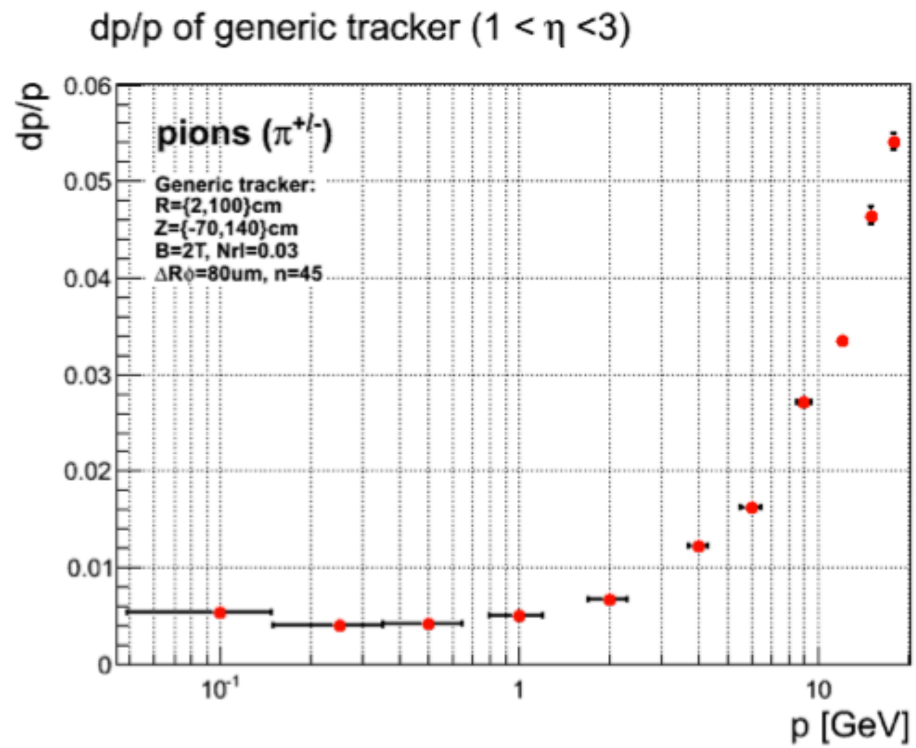
Forward

B = 2 T

Res = 20 um



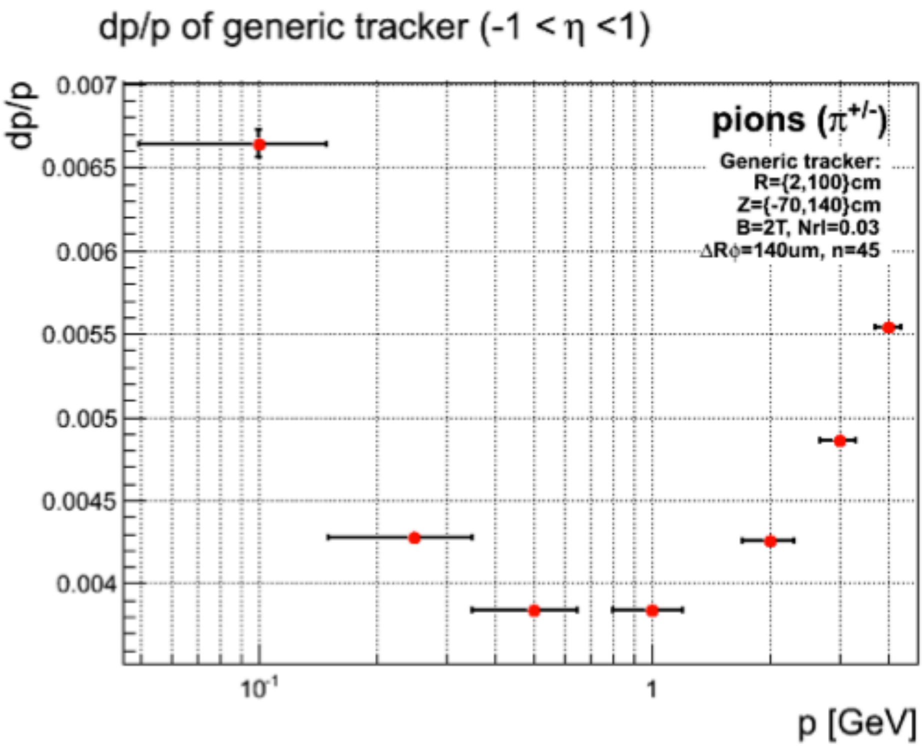
Central



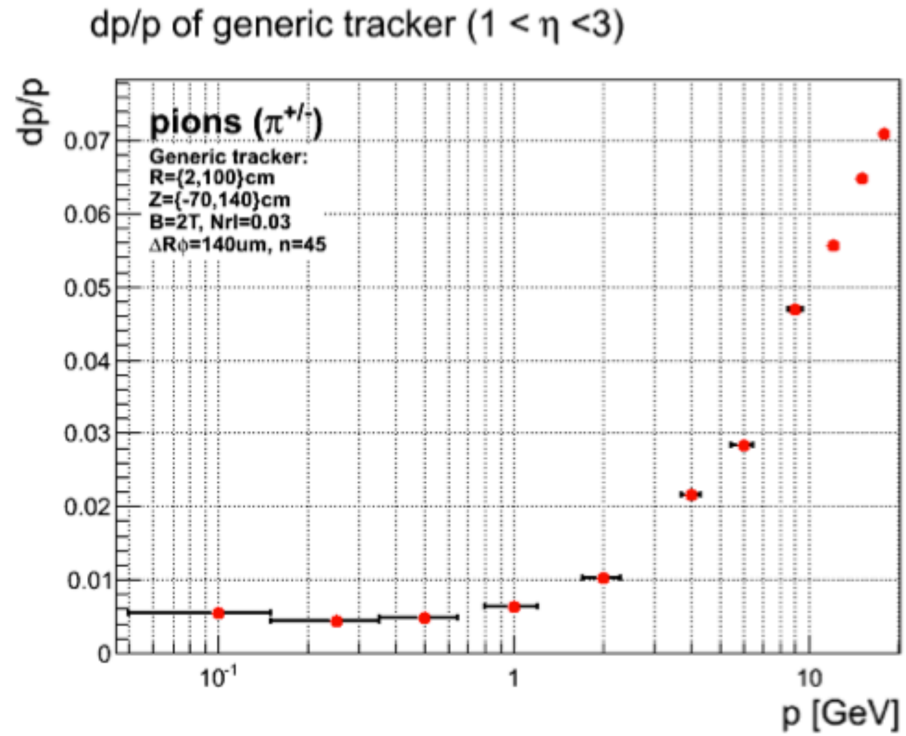
Forward

B = 2 T

Res = 80 um



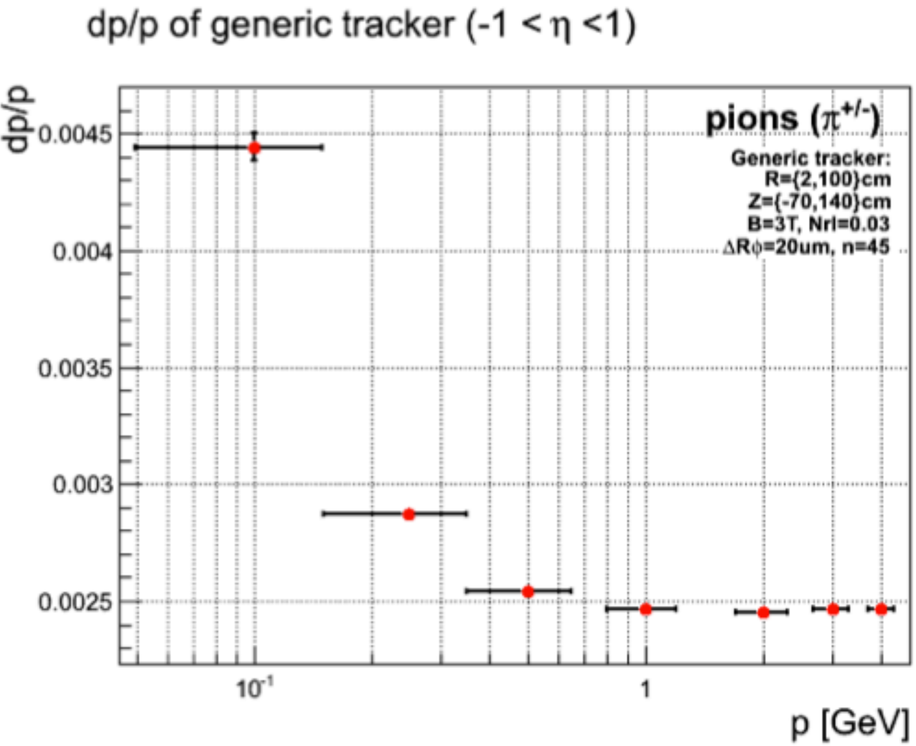
Central



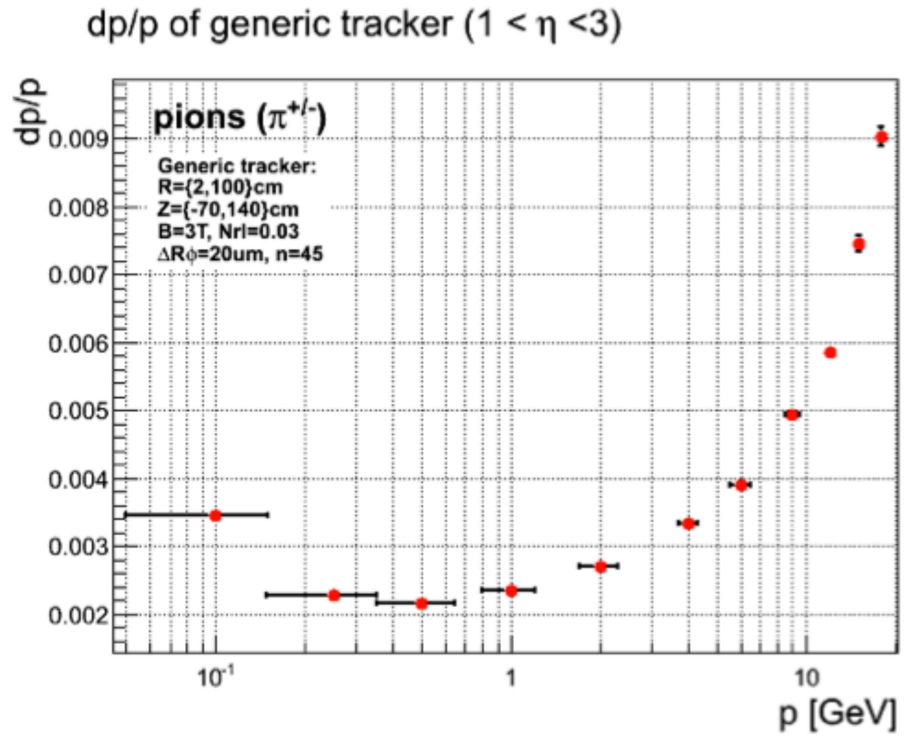
Forward

B = 2 T

Res = 140 um



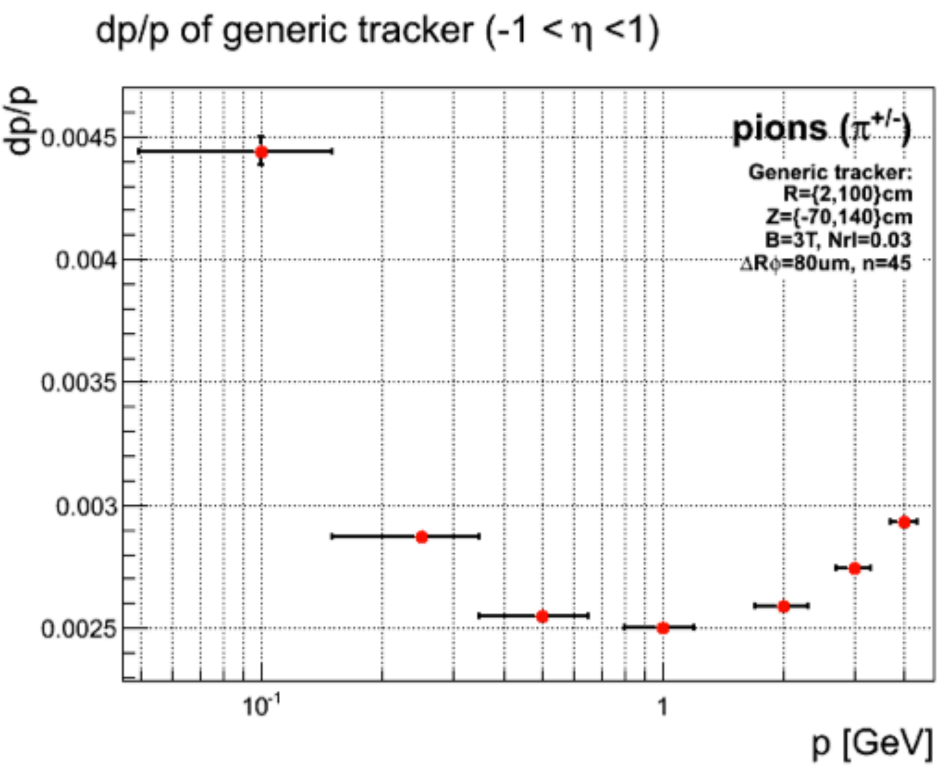
Central



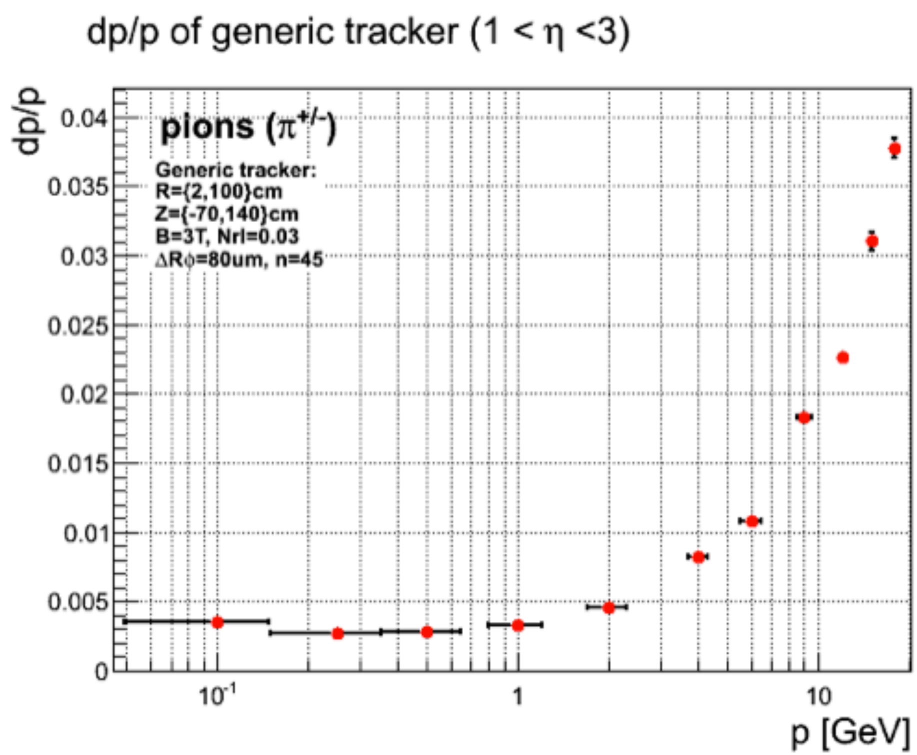
Forward

B = 3 T

Res = 20 um



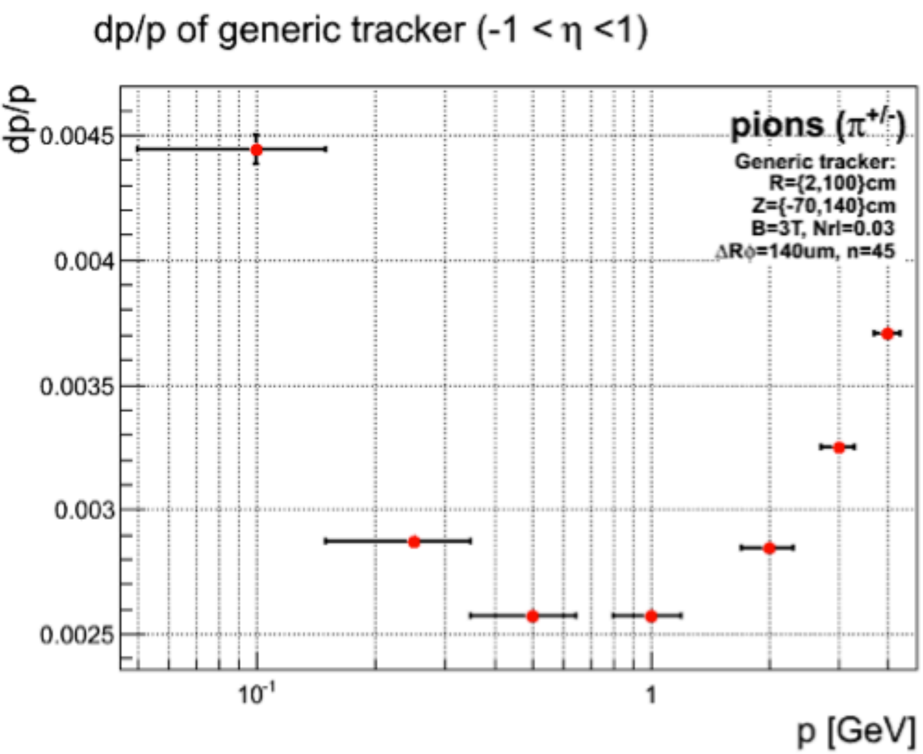
Central



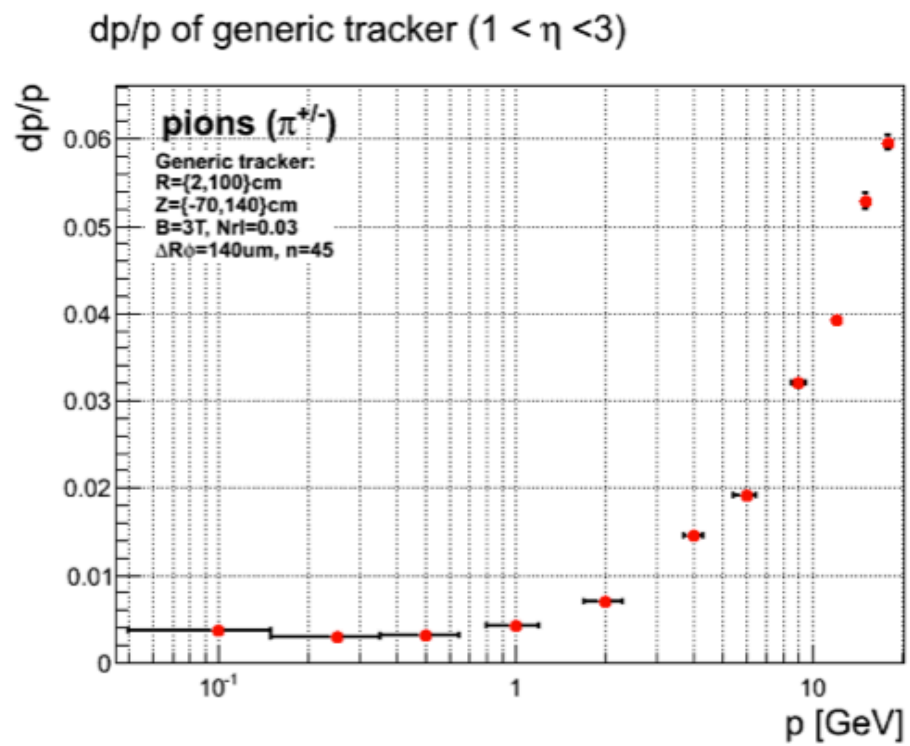
Forward

B = 3 T

Res = 80 um



Central



Forward

B = 3 T

Res = 140 um

Detector script snippets

/eicdata/eic0003/wforeman/smear/[detectorfile].c

```
// EM Calorimeters

Device EMCal_barrel(kE,"0.122*sqrt(E)",1);
EMCal_barrel.Accept.AddZone(central);

Device EMCal_endcap(kE,"0.0178*sqrt(E)+0.0069*E",1);
EMCal_endcap.Accept.AddZone(forward);
EMCal_endcap.Accept.AddZone(backward);
```

```
// Hadronic calorimeter (for now assume HERA)
Device HCal(kE,"0.35*sqrt(E)",2);
```

```
// Tracking

PlanarTracker PlanarTrack_backward(0.02,0.20,-1.0,-0.5, B, 0.03, res, 6);
PlanarTrack_backward.Accept.AddZone(track_b);

PlanarTracker PlanarTrack_forward( 0.02,0.20, 0.5, 1.0, B, 0.03, res, 6);
PlanarTrack_forward.Accept.AddZone(track_f);

RadialTracker RadialTrack( 0.20,1.0,-1.0,1.0,B, 0.03, res, 40);
RadialTrack.Accept.AddZone(track_c);
```

Sources

- Calorimeters
  - https://wiki.bnl.gov/conferences/images/9/96/RD2012-14_Joint-Proposal-Calorimeter-2012.pdf
  - https://indico.bnl.gov/getFile.py/access?contribId=6&sessionId=2&resId=0&materialId=slides&confId=450
  - https://wiki.bnl.gov/conferences/images/5/51/RD_2011-2_Crystal-USTC.pdf
  - http://www-zeus.desy.de/public/hera-phy.php3
- Tracking resolution
  - http://www-jlc.kek.jp/subg/offl/lib/docs/helix_manip/node32.html#SECTION00600000000000000000
  - http://pdg.lbl.gov/2011/reviews/rpp2011-rev-particle-detectors-accel.pdf
  - "A Possible Design for a Forward RICH" – E.C. Aschenauer, STAR Upgrade Workshop, UCLA, December 2011